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Thickness and Stack Height Measurement Uncertainty of Experimental Packages for National Ignition Facility Targets

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Introduction

Targets for experiments carried out at the National Ignition Facility (NIF) [1] often incorporate millimeter-scale stacks of various materials with individual thicknesses that can be as small as a few micrometers. Thickness measurements of both the individual components, as well as any included glue lines or gaps, are essential for successful experiments and data analysis. Part geometries and materials necessitate multiple measurement techniques that must be combined to infer micrometer-scale glue thicknesses from stack height measurements. Furthermore, form variation in thin parts makes quantifying errors challenging. Here, we discuss issues involved in the metrology and uncertainty quantification for these types of experimental packages.

Target materials of interest include low density foams, metal foils and transparent crystalline solids. Typically, the components contain precision manufactured features such as steps, slots or sine waves [2], and multiple components are assembled in a stacked geometry illustrated in Figure 1. Tolerances for these parts and assemblies are often at, or below, the micrometer level for feature dimensions, thickness and form similar to values seen MEMs type of applications [3].

For many targets, the stacks are assembled with micrometer-scale glue layers, which are too thin to be measured directly with techniques such as optical or x-ray microscopy. While the individual stack components can be readily measured with tools such as measuring microscopes and touch probes, metrology of the assembled stack presents challenges because glue layer thickness and uniformity must be inferred from indirect measurements.

Measurements and Methods

In general, both contact and non-contact metrology methods are used in combination to evaluate the individual parts and assemblies at various stages of the assembly process. A variety of instruments including "on-machine" gauging techniques are used throughout the manufacturing process. The variation in measurement uncertainty between contact and non-contact metrology for the large variety of materials used in an experimental package adds directly to the overall measurement uncertainty and represents the focus of this work.

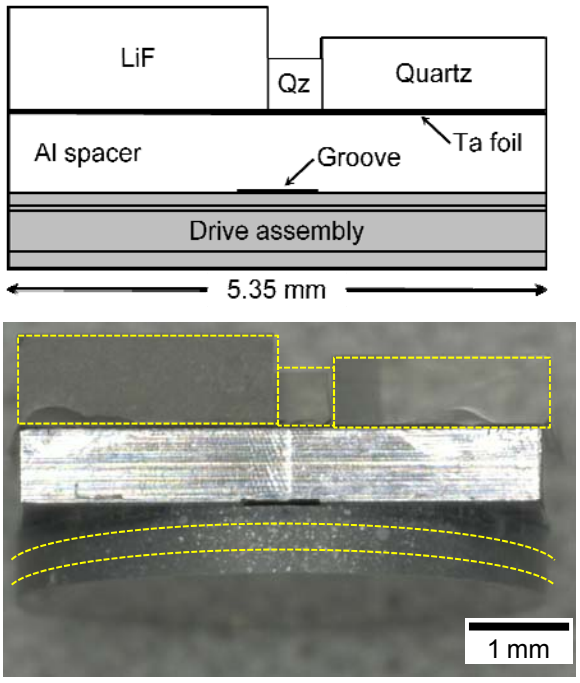

FIGURE 1. Scale drawing of experimental package shown in the photograph above. The LiF and quartz (Qz) windows are transparent. The drive assembly consists of CH, 12.5 at. % BrCH, and two densities of carbon foam; these layers are encapsulated in epoxy, and appear as one layer in the photograph.

Typically, thickness and form measurements are done by placing the part or assembly onto a reference surface, typically a gage block, Si or optical flat and use a contact or non-contact probe technique to relate features of interest on the part to the reference surface. Common technologies used include white light interferometry (WLI), laser probes, and both uni-directional and multi-directional contact probes.

Figure 2 illustrates the types of features and form error that needs to be characterized as part of the overall assembly. In this case, Tantalum steps have been deposited onto a polycrystalline carbon substrate. Figure 2 c) shows a lineout of the measured sample. Figure 2 d) is the ideal profile based on the design. Residual stress of the coating process has caused the substrate to warp and crack as shown in b). In this case there in approximately 100 μm of form on a nominally 100 μm thick sample. The ability to deconvolve thickness variation or gaps from form error is a key requirement for understanding the experimental data.

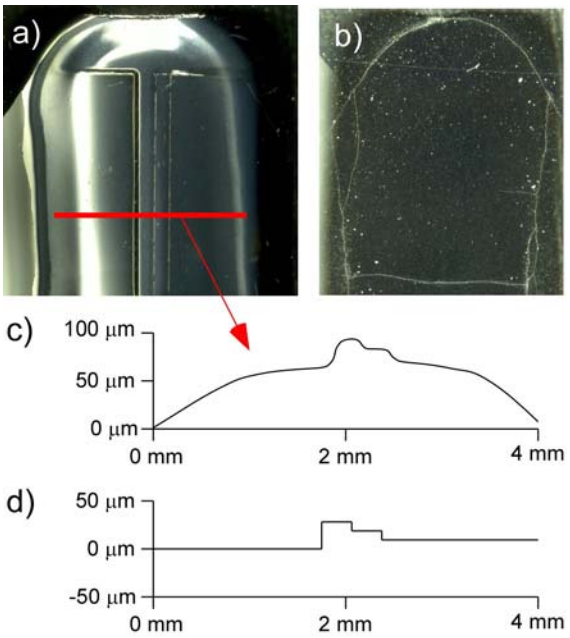

FIGURE 2. a) Photograph of stepped Ta coated onto a polycrystalline carbon substrate. b) Backside photograph of Ta coating showing cracking on the periphery. c) Lineout across the steps of the Ta part (data smoothed) d) Illustration of the ideal lineout.

Other methods of making these types of measurements include x-ray computed tomography (CT) and opposing probe techniques. [4, 5] However, these techniques are beyond the scope of this effort.

Analysis

To quantify the task specific measurement uncertainty of these techniques, three grade 00 gage blocks with an expanding uncertainty of 60 nm were wrung together to create a stepped sample, shown in Figure 3. This sample was then measured by two different WLIs, OCMM with laser probe, and an automated contact based length gage. Table 1 lists the manufacturer's instrument specification for each instrument used in this study.

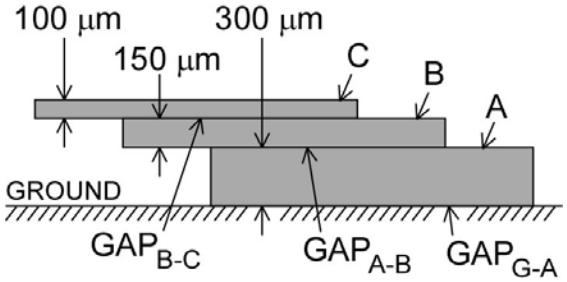

FIGURE 3. 300 μm, 150 μm and 100 μm grade 00 gage blocks wrung together and placed on a ground steel substrate. The ground reference surface has a surface finish 10 nm Ra of and flatness of 50 nm.

Each step is measured relative to the reference surface (ground) by each of instruments being employed. The gage length including errors associated with the gage block artifact measurements can be expressed by

$$L_{GA} = L_A + \delta_A + \delta_{GA}, \quad (1)$$

$$L_{GB} = L_{GA} + L_B + \delta_B + \delta_{AB}, \quad (2)$$

$$L_{GC} = L_{GB} + L_C + \delta_C + \delta_{BC}, \quad (3)$$

where L_A, L_B, and L_C are the accepted lengths of the gage blocks, δ_A, δ_B, and δ_C are the gage block errors and δ_{GA}, δ_{AB}, and δ_{BC} represent the errors/gaps between the ground and gage A, gage A and gage B and gage B and gage C respectively. Removing the accepted gage block length, the errors associated with the artifact are given by

$$E_{GC} = \delta_A + \delta_{GA} + \delta_B + \delta_{AB} + \delta_C + \delta_{BC}. \quad (4)$$

In the general case, where stacks of various materials with different interfaces, Eq 4 can be written as

$$E_{0,n} = \sum_{i=1}^{n} \delta_i + \sum_{i=0}^{n} \delta_{i,i+1}, \qquad (5)$$

where δ_i, is the error associated with each individual part in a stack and $\delta_{i,i+1}$, is the error/gap of each interface in the assembly stack of interest.

For the analysis presented in this abstract, δ_A, δ_B, and δ_C are the expanded uncertainties of each of the three gage blocks given by the calibration certificate as (0.06+0.5*L/1000) µm where L is in mm. The surface finish and flatness of the gage blocks used were less than 10 nm Ra and 50 nm respectively. Considering the lengths of the gages in use, 60 nm was used as the gage expanded length uncertainty.

TABLE 1: Instrument specifications used for single sided thickness measurements.

Instrument	Manufacturer Specification	Range (mm)	Probe Type
OCMM	1.5+L/150 µm (L in mm)	250	Laser
Length Gage	1 µm (0.5 µm res)	12	Stylus
WLI (1)	0.025 µm (over 500 µm range)	8	Interferometer
WLI (2)	0.025 µm (over 500 µm range)	12	Interferometer

Results

The gage block sample was measured ten times using each of the four measurement systems described in Table 1. Each measurement was done in a temperature controlled class 1000 clean room with a ΔT of less than ± 1.0 C°. Considering the a thermal expansion coefficient of 11.5 e^{-6} m/m°C [6] the total variation of the gage block length due to temperature variations is approximately 12 nm and considered negligible for this comparison.

The interface errors were solved using eqs (1-3) and accepting the expanded uncertainty of the gage block thickness to be 60 nm. It was expected that the interface errors between gages would be consistent with those commonly found in literature, which have been reported to range anywhere from 6 nm to 50 nm [7].

Figure 4 shows the results of gap error for each instrument sampled ten times, removing the sample and replacing it each trial. The automated length gage (gage) was operated using three different trigger settings labeled as gage #1, gage #2 and gage #3. It was clear from the data that the error between the sample and the ground or reference surface was large compared to the relative gap between gage blocks, as expected. However the errors or gaps between gage blocks were larger than expected and represent the types of gaps or errors that need to be quantified to the micrometer level.

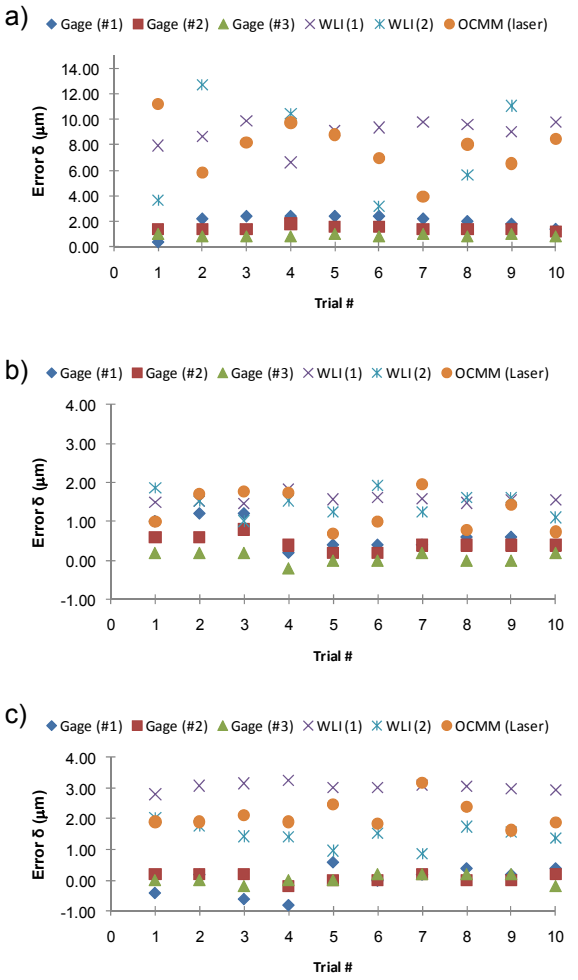

FIGURE 4. Plots of the measured gap errors a) Error between the reference surface and gage block A. b) Error between gage A and gage B. c) Error between gage B and gage C.

The average and standard deviation for each gap measurement is shown in Table 2. Clearly

the contact based measurements lowered the influence of the gaps, primarily between the reference surface and the first gage. However, the measurement technique is influencing the measurement on the order of the values of interest and may or may not provide the information required to relate pre-experiment characterization to the post-experiment data.

TABLE 2. Average and standard deviations of the gap measurements.

	δ_{GA} (μm)		δ_{AB} (μm)		δ_{BC} (μm)	
Instrument	Ave	σ	Ave	σ	Ave	σ
Gage (#1)	2.0	0.6	0.7	0.4	0.02	0.5
Gage (#2)	1.5	0.2	0.5	0.2	0.1	0.1
Gage (#3)	0.9	0.1	0.1	0.1	0.04	0.1
WLI (1)	8.98	1.02	1.57	0.11	3.03	0.12
WLI (2)	12.25	6.69	1.47	0.31	1.47	0.35
OCMM (laser)	7.8	2.0	1.3	0.5	2.0	0.5

Future Work

The authors are currently working on different artifacts to evaluate performance of the optical based systems with multiple reflective surfaces, such as quartz or lithium fluoride (LiF). Another white light interferometric system has been developed and is being qualified (see reference [5]) below the micrometer level.

Summary

As expected, there is a relatively large error (4 μm to 12 μm for non-contact and 1 μm to 3 μm for contact measurements) between the reference surface and the gage block sample. The contact probe techniques reduce the gap error within the limits of instrument accuracy. However, because of the types of materials used in target assemblies this is often not a credible option without damaging or plastically changing the part geometry during the measurement process. In addition, the influence of the probe on the part can produce values not

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